

**UTILITY APPLICATION**

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**OF**

**YIPING HU**

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**ON**

**COAXIAL NOZZLE DESIGN FOR LASER  
CLADDING/WELDING PROCESS**

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## COAXIAL NOZZLE DESIGN FOR LASER CLADDING/WELDING PROCESS

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### Cross-References to Related Applications

This patent application incorporates by reference, but claims no priority to the following patents and regular and provisional patent applications:

United States Patent Application Serial Number 10/071,025 filed February 8, 2002 for Hand Held Laser Powder Fusion Welding Torch; and

United States Patent Application Serial Number 10/206,411 filed July 26, 2002 for Powder Feed Splitter for Hand-Held Laser Powder Fusion Welding Torch.

## BACKGROUND OF THE INVENTION

### Field of the Invention

This invention relates to powder fusion welding and more particularly to a coaxial nozzle for use in laser powder fusion welding (LPFW) processes.

### Description of the Related Art

In general, the surface of a metallic article may be welded and/or alloyed by the simultaneous and cooperative operation of a laser beam and an alloy powder stream. To accomplish this, systems exist that have a laser source and focusing apparatus, with a powder delivery apparatus provided as part of an integral package. The laser beam melts a relatively small area at the surface of the article, and a controlled volume of alloying particles are delivered into the melt pool via the powder flow stream.

In laser fusion welding, an article of metal or other material may have the surface thereof alloyed, or otherwise treated, by the simultaneous and cooperative operation of a laser beam with an alloy powder. Typically, the laser beam melts a relatively small volume of the outer

surface of the article and the powder feeding system delivers a controlled volume of alloying particles into this molten pool. The alloying particles become dispersed throughout this pool and therewith alter, complement, or add to the composition of the outer layer in a controllable way. Removal of the beam, such as by advancement of the workpiece relative to the laser beam, can cause the molten metals to be rapidly cooled. The cooling can occur so rapidly that the clads or welds retain the characteristics of the molten metal.

With the increased use of lasers to provide free-form powder fusion welding, articles can be constructed having near-net shape. This provides significant advantages as compared to casting or other component-making processes.

In a powder fusion process, powder filler material is fed to the irradiated area of the welding tool, usually a laser or other energy source. The powder may contain a variety of different substances including particulate metals and composites. Generally, a powder feeder is used to deliver the filler powder to the welding torch. In some cases, the powder flow stream is split into several substreams and transported to the welding torch through several different flow trajectories in order to form cone-shaped powder stream outside the welding torch. The filler powder is generally delivered to the welding torch by a pressurized gas, such as an inert or non-reactive gas such as helium and argon.

As an example, gas turbine engines, such as those utilized with jet aircraft, are being designed with ever increasing performance requirements. Laser powder fusion (LPF) technology has been in use for the past several years and has demonstrated benefits by welding previously unweldable materials and on small heat affected zones on turbine airfoils. Other parts and machines can also benefit from the use of LPF technology. However, there have been some drawbacks in certain elements in LPF welding systems, including the nozzle that serves to bring together both the laser light that performs the welding as well as the powder which is used to construct the weld. Such nozzles often provide a circumscribing "curtain" of flowing inert gas which temporarily and effectively shields the weld site from oxygen and other gasses and materials, which can interfere with the welding process and/or the integrity of the resulting weld.

Some known nozzle designs have many drawbacks. For example, nozzle inserts used in some nozzles may easily burn, may take an undue amount of time to replace the inserts or to align the beam, and/or the overall function is not consistent. Such nozzles are generally not suited for many applications.

For some prior nozzles, the bottom edge of the inner insert is so thin or sharp that it may not tolerate heat reflected from the welding zone. Therefore, the inner insert may be damaged

during the laser welding process. This may be especially noticeable when welding on an inclined surface where severe laser beam reflection occurs. It can take a few hours or more to replace such nozzle inserts which can be costly.

5 In some cases, the inner insert sustains only minor damage. For example, the edge may fold outwards slightly due to the cleaning process or otherwise. This minor damage does not affect the powder feed rate, but it does change the powder stream shape, which should be cone-shaped at the nozzle exit. Such damage can also reduce the powder utilization efficiency, since less powder may flow to the welding zone. This can lead to two possible results, both of which are unacceptable: the weld is hot and material buildup is less, and/or cracking is created inside  
10 the weld. Because such prior nozzles' performance are not consistent, delays in production may occur that increase production time by days.

In addition, a shielding plate may play an important role in the laser welding process. The shielding plate in some prior nozzles is made of sintered copper with micropores. During the laser welding process, molten particles or plasma fumes may seal the micropores and make  
15 the nozzle's function inconsistent and unreliable.

In view of the several disadvantages present in current laser nozzles, additional costs and time are spent in order to accommodate the frequent failures that arise when such prior laser nozzles are actually used in welding processes. These shortcomings in prior laser nozzles have acted as an impediment to laser welding processes and the advancement of the laser powder  
20 fusion welding arts. As laser powder fusion welding provides reliable means by which near-net parts can be achieved as well as repairing parts that would otherwise be scrapped or discarded, there is a need in the art to provide a laser powder fusion welding nozzle that can better withstand the welding operations for which it is designed.

In view of the foregoing disadvantages, there is a need for an improved laser powder  
25 fusion welding nozzle that operates in a reliable and robust manner with a tip that does not fail on a recurring basis. It would also be advantageous to have such a laser powder fusion welding nozzle that did not suffer injury or damage during the welding process which leads to asymmetrical powder feeding into the irradiated area. The present invention solves one or more of these disadvantages and satisfies a need for better laser powder fusion welding nozzles that is  
30 presently in the art.

## SUMMARY OF THE INVENTION

In view of the foregoing disadvantages, the present invention provides a laser powder fusion welding nozzle wherein the nozzle can be used for a longer period of time in welding

processes and the like. In particular, a new laser powder fusion welding nozzle is provided that does not require the replacement of nozzle inserts, does not as frequently sustain nozzle tip deformation, and provides more reliably-symmetric powder flow, overcoming several of the disadvantages present in the prior art by combining many novel features in order to achieve a new laser powder fusion welding nozzle design.

Knowledge and experience in the field of laser cladding/welding process has led to the present design. Compared with prior nozzles, the present nozzle design has the following advantageous features: it is easy to clean inside the nozzle; it provides better shielding during laser welding; it eliminates the use of nozzle inserts; the powder stream interacts with laser beam outside the nozzle; it is easy to adjust the laser focus distance in order to get different laser spot sizes; and it is easy to adjust the positioning of cone-shaped powder stream with respect to the center of laser beam.

Because nozzle inserts are not used in the present nozzle design, the nozzle does not need replacement and beam alignment that would arise from use of such inserts. The new nozzle design has many advantages (mentioned above) over prior nozzles which are believed to enable nozzle performance that is significantly advanced.

The laser powder fusion welding nozzle has a variety of coaxial features that generally center upon the linear axis on which the laser beam travels. Conveniently, the central passageway of the nozzle through which the light travels provides enough radial space to enable laser beams of different cross sections to constructively use the nozzle.

The main body has cut into it a coolant chamber through which coolant may flow. This coolant channel is covered by a coolant jacket or water jacket cover that is detachably attached to the top of the main body by fasteners such as screws. The coolant jacket cover has indentations or depressions in oppositely opposed or orthogonal pairs in which powder tubes rest. The powder tubes communicate with powder conduits that travel through the main body and exit out the other side. The main body is pointed in a stepwise fashion ending in a final terminal end about which the inner tip detachably attaches as by threaded engagement, or otherwise. Although the materials used are preferably of the type like copper alloy, detachable attachment as by threaded engagement is very convenient as it provides for separation for the necessary channels (described below) while allowing easy disassembly and reassembly for cleaning and reconfiguration.

The intermediate step of the main body is circumscribed by an outer nozzle. While the laser light travels through the central passage of the main body and the inner tip, the area between the inner tip and outer nozzle provides a channel through which powder can flow as

this powder flow channel is in communication with the powder conduits of the main tip. Circumscribing the entire main body nozzle assembly is a housing which acts as an outer gas containment sleeve and provides a shield gas flow channel between its interior and the exterior of the outer nozzle. The housing is attached to the main body by screws or the like. Inlets are present at the sides of the containment sleeve for the introduction of shield gas, generally an inert gas.

In order to protect the welding zone, inert gas flows through a porous shielding cover. The porous shielding cover better distributes to provide more uniform distribution of the inert gas. The porous shielding cover is held in place by a snap ring which fits into a groove engraved at the mouth of the housing.

A body O-ring provides a seal between the main body and the housing. Inner and outer coolant jacket O-rings are present to provide positive seals for the coolant channel in the main body. The O-rings are generally made of BUNA-type rubber.

In one embodiment, the laser nozzle for powder feed laser welding has an inner tip that resists damage arising from heat generated during a welding process. An outer nozzle circumscribing the inner tip in spaced apart relationship defines a circumscribing powder flow channel about the inner tip. An housing circumscribes the outer nozzle in spaced apart relationship to define a circumscribing shield gas flow channel about the outer nozzle such that the laser nozzle enjoys a longer useful life and provides more efficient welding as the inner tip is less susceptible to damage from the welding process.

In another embodiment, the laser nozzle for powder feed laser welding has a detachable inner tip that resists damage arising from heat generated during a welding process. A detachable outer nozzle circumscribes the inner tip in spaced apart relationship to define a circumscribing powder flow channel about the inner tip. A detachable housing circumscribes the outer nozzle in spaced apart relationship to define a circumscribing shield gas flow channel about the outer nozzle. A main body couples the inner tip, the outer nozzle and the housing. The main body defines a central passage through which light may travel, defines a powder flow conduit in communication with the powder flow channel, and defines a coolant channel coaxial with the central passage. A detachable water jacket cover couples to the main body and encloses the coolant chamber to prevent coolant leakage. The water jacket cover defines a powder tube depression through which a powder tube may pass and communicate with the powder flow conduit. A detachable porous shielding cover is coupled to and circumscribes the outer nozzle. The porous shielding cover allows gas to exit from the shield gas flow channel in a more uniform manner. The porous shielding cover is circumscribed by and is coupled to the

housing such that the laser nozzle is easier to clean and maintain and enjoys a longer useful life and provides more efficient welding as the inner tip is less susceptible to damage from the welding process.

In another embodiment, the coaxial nozzle for laser powder fusion (LPF) welding has a  
5 main body defining a central light passage through which light may pass through the main body. The main body defines a powder conduit through which powder may pass through the main body. The main body defines a coolant channel through which coolant may flow, the coolant chamber coaxial with the central light passage and circumscribing the powder conduit. A coolant jacket cover detachably attaches to the main body and seals the coolant channel, the  
10 coolant jacket defining an inlet and an outlet to the coolant channel. An inner tip defines a first central open channel through which light may pass, the inner tip detachably attached to a terminal end of the main body. The inner tip is coaxial with the central light passage of the main body. An outer nozzle defines a second central open channel through which powder may pass, the outer nozzle detachably attached to the main body. The outer nozzle is coaxial with  
15 the first central open channel of the inner tip and the central light passage of the main body. A powder flow channel is defined between the outer nozzle and the inner tip and is in communication with the powder conduit. A housing defines a third central open channel through which inert gas may pass, the housing detachably attached to the main body. The housing is coaxial with the second central open channel and the first central open channel and  
20 the central light passage. A shield gas flow channel is defined between the outer nozzle and the housing. A detachable porous shielding cover circumscribes a terminal end of the outer nozzle and covers an open end of the shield gas flow channel.

In another embodiment, a nozzle for powder feed laser welding has a detachable and heat-resistant tip that resists damage arising from heat generated during operation, the tip having a  
25 first central light passage. The nozzle defines a second central light passage aligned and communicating with the first central light passage. The nozzle defines a powder flow passage circumscribing and coaxial with the central light passage. The nozzle defines a shield gas flow passage circumscribing and coaxial with the powder flow passage and the central light passage. A detachable porous shielding cover covers an open end of the shield gas flow passage  
30 proximate the tip.

Other features and advantages of the present invention will become apparent from the following description of the preferred embodiment(s), taken in conjunction with the accompanying drawings which illustrate, by way of example, the principles of the invention.

## **BRIEF DESCRIPTION OF THE DRAWINGS**

Figure 1 is a vertically exploded view of the laser powder fusion (LPF) welding nozzle, the drawing exploded along the central vertical axis.

Figure 2 is a first side elevational view of the LPF nozzle of Figure 1 as assembled.

Figure 3 is a second side elevational view of the LPF welding nozzle of Figure 2.

Figure 4 is a side cross sectional view of the LPF welding nozzle of Figure 3 taken along the line 4-4 of Figure 3.

Figure 5 is a top side perspective view of the LPF nozzle of Figure 2.

Figure 6 is a bottom side of the LPF welding nozzle in Figure 2.

Figure 7 is a bottom plan view of the LPF welding nozzle of Figure 2.

Figure 8 is a top plan view of the LPF welding nozzle of Figure 2.

## **DESCRIPTION OF THE PREFERRED EMBODIMENT(S)**

The detailed description set forth below in connection with the appended drawings is intended as a description of presently-preferred embodiments of the invention and does not represent the only forms in which the present invention may be constructed and/or utilized. The description sets forth the functions and the sequence of steps for constructing and operating the invention in connection with the illustrated embodiments. However, it is to be understood that the same or equivalent functions and sequences may be accomplished by different embodiments that are also intended to be encompassed within the spirit and scope of the invention.

As best shown in Figures 1 and 4, the coaxial laser powder fusion (LPF) welding nozzle **100** has a main body **102** which generally serves as a core element and helps to receive and guide both the powder used for laser fusion (not shown) as well as having a central channel **104** through which the laser light passes. The main body **102** is capped or covered by a coolant jacket cover **106** which detachably attaches to the main body **102** by means of fasteners **108**. A flat washer **110** and a BUNA washer **112** circumscribe the fasteners **108** in order to provide a seal for the fastener holes **122** passing through the coolant jacket cover **106** which seals the coolant chamber **114** cut into the main body **102**. An inner coolant jacket cover O-ring **116** and an outer coolant jacket cover O-ring **118** served to provide a positive seal between the coolant jacket cover **106** and the main body **102** over the coolant channel **114**.

BUNA N or Nitrile is a copolymer of butadiene and acrylonitrile and may be used to construct the BUNA washer **112**. On the whole, most of the parts are generally made of copper alloys or other resilient material. The main body **102**, the coolant jacket cover **106**, and the housing **190** may be made of brass. The inner tip **140** and the outer nozzle **160** may be made of

copper. The body O-ring **182** and the inner **116** and outer **118** coolant jacket cover O-rings may be made of BUNA rubber. The flat washer **110**, fasteners **108**, powder tubes **132**, and screws **192** may be made of stainless steel. A coolant jacket cover **106** has indentations or depressions **130** into which powder tubes **132** fit. The powder tubes **132** are inserted into and communicate  
5 with powder conduits **134** which travel through the main body **102**.

As shown particularly in Figure 1 and 4, the main body **102** has a pointed configuration achieved in a stepwise fashion. As shown in Figure 4, the main body **102** may be considered as having a top cylindrical portion with a wider radius, a middle cylindrical portion having a smaller radius and an inner portion having the smallest radius. The terminal projection **136**  
10 circumscribes a continuation of the central channel **104** and is itself circumscribed by the inner tip **140** which circumscribes its own tip channel **142** that enables the laser light passing through the central channel **104** to exit the nozzle **100**. The inner tip **140** may detachably attach to the terminal projection **136** by threaded engagement or otherwise with the terminal projection **136** having threads **144** circumscribing its base into which matching threads **146** which  
15 circumscribe the top interior of the inner tip **140** may fit. The inner tip **140** is detachably attachable to the main body **102** at the terminal projection **136** thereof.

Circumscribing the middle portion of the main body **102** is an outer nozzle **160** which also has inner threads **162** circumscribing the inner top surface of the outer nozzle **160**. The threads of the outer nozzle **160** may engage matching outer threads **164** that circumscribe the  
20 base perimeter portion of the middle portion of the main body **102**. The outer nozzle **160** may detachably attach to the middle portion of the main body **102** by means of a threaded engagement or otherwise provided between the matching threads **162**, **164**.

The inner tip **140** is radially inside of the powder conduits **134** and is closer to the central channel **104** than the powder conduits **134**. Consequently, the inner tip **140** does not interfere  
25 with the flow or egress of powder through the powder tubes **132** or the powder conduits **134**. The powder conduits **134** communicate with a plenum space or channel **170** defined between the inner tip **140** and the outer nozzle **160**. This plenum space is defined by the surfaces of the inner tip **140** and the outer nozzle **160**. Fluid flow, including the flow of fusion powder, from the powder flow channel **170** may be focused on the main axis and light travel path passing  
30 through the central channel **104**. As the powder flow channel **170** is coaxial with the central channel **104** and its vertical axis, and as the laser light will travel generally along this vertical axis centered on the central channel, powder traveling through the powder flow tubes **132** powder conduits **134** and powder flow channel **170** will generally be coincident with the laser light at some location beyond the LPF nozzle **100**. This location, which may be referred to as

the powder flow convergent point, will be generally and immediately in front of the inner tip **140** and its tip channel **142**. Adjustment of the powder flow focal point may be achieved by proper selection and geometry of the inner tip **140** and the outer nozzle **160**.

Engraved in the side of the main body **102** is a groove **180** into which a body O-ring **182** fits. The O-ring **182** serves to provide a seal between the main body **102** and the housing **190**. The housing **190** may serve as a holder for the main body **102** as well as an envelope within which shield gas may flow which shields the welding operation that takes place in front of the tip channel **142**. The housing **190** may also serve as a mechanical support and point of attachment for the nozzle **100** to a laser system, powder feed system, cooling system, and the like. However, an automated welding system or other control system (not shown) may attach by threaded engagement of the inside of the main body **102** along the inside surface **198** of the central channel **104**.

The housing **190** attaches to the main body **102** by means of screws **192** placed near the top of the containment sleeve **190** as shown in Figure 4 or otherwise. A connector or other device may be used to connect a gas supply to the containment sleeve **190**. Inlets **194** allow the pressurized flow of inner shielding gas or the like to travel into the confines of the containment sleeve **190**. The outer nozzle **160** serves as the inside of the shield gas flow channel **196** which has its exit near the mouth of a nozzle **100** circumscribing the outer nozzle **160** as well as the powder flow channel **170**.

A porous shielding cover **210** covers the exit of the shield gas channel **196** and helps to ensure that ejecta or other material from the welding site does not enter into the shield gas channel **196**. The porous shielding cover enables the shield gas to flow through it and onto the welding site in order to protect the welding site from oxidation but does not allow the reverse passage or flow of ejecta or other material back into the shield gas flow channel **196**. The porous shielding cover **210** is held in the groove etched into the mouth **212** of the nozzle **100** by a snap ring **214** which likewise fits into its own groove machined into the mouth **212** of the nozzle **100**. A corresponding groove opposite that engraved in the containment sleeve **190** for the porous shielding cover **210** may be present in the outer nozzle **160**. The porous shield and cover **210** is held in place by the snap ring **214** between the outer nozzle **160** and the housing **190**.

In order to dismantle the LPF welding nozzle **100**, the snap ring **214** may be disengaged from the housing **190** thereby freeing the porous shielding cover **210**. The porous shielding cover **210** is then removed. The clamping screws **192** are then loosened by unthreading them slightly from the housing **190**. The main body **102** may then be removed from the housing **190**.

The outer nozzle **160** and the inner tip **140** may be removed as by unthreading from the main body **102**. The body O-ring **182** may be removed from its groove **180** and the fasteners **108** may be unthreaded from the main body **102**. This frees the coolant jacket cover **106** from the main body **102** and the inner **102** and outer **118** coolant jacket cover O-rings maybe freed from their seats. Prior to removal of the coolant jacket cover **106**, the powder tubes **132** may be unseated from their inserted positions in the main body **102**. The outward cant of the powder tubes **132** may prevent the removal of the coolant jacket cover **106**. A friction fit may be present by the powder tubes **132** into the main body **102** or more permanent means of fixing the powder tubes **132** to the main body **102** may be used. However, permanent fixation of powder tubes may interfere with the disassembly of the coolant system.

Assembly of the nozzle **100** may be achieved by a general reversal of the disassembly sequence set forth above or by a general inspection of the figures.

Having set forth the construction and structure of the nozzle **100**, its operation is set forth below. The nozzle **100** is connected to a laser powder fusion (LPF) welding system such that the laser light of the welding system passes through the central channel **104** and out the inner tip **140** through the tip channel **142**. This laser light is sufficient to melt or alter either or both the substrate material upon which the weld is to be performed and/or the powder fusion material passing through the nozzle **100**.

The powder fusion material is generally propelled by pressurized inert gas, generally the same inert gas that is pumped through the shield gas flow channel **196**. Inert gases are used so that they do not react with the powder or the substrate material at the weld site. The powder material enters into the nozzle through the powder tubes **132**, travels through the powder conduits **134**, flow into the powder flow channel **170** and then exits the mouth **212** of nozzle **100** in a generally conical fashion circumscribing the tip channel **142** of the inner tip **140**.

When the filler material exiting out the powder flow channel **170** meets the laser light, it is melted and then may fuse with the spot melt present at the weld site to augment the material pooling there. The weld site with its melt pool is shielded from chemical reaction by an inert ambient environment provided by the flow of inert gas through the shield gas flow channel **196** and its exit through the porous shielding cover **210** as it exits out of the mouth **212** of the nozzle **100**. The porous shielding cover **210** generally provides for uniform distribution and diffusion of the inert shielding gas without significant turbulence. Sufficient shielding gas volume should be provided to ensure that the hot weld area does not react with ambient gases or otherwise.

During the welding operation, heat is generated that may be transmitted to the nozzle **100**. In order to keep the nozzle **100** cool, coolant is circulated within the main body **102** in the

coolant channel **114**. Coolant inlets **220** are present in the top of the coolant jacket cover **106** and allow the entrance and exit of coolant, particularly water, into and out of the coolant channel **114**. The circulation of coolant in the coolant channel **114** enables the main body **102** to be kept cool and to endure longer and/or hotter welding operation sessions.

Note should be taken that the embodiment set forth above is only one of several possible embodiments of the present system that enable the use of a more robust tip to prevent the ongoing and inconvenient replacement of nozzle inserts and the like in order to provide longer operation of the nozzle **100** without suffering interruption. In other embodiments, both inner tip **140** and outer nozzle **160** may be replaced by ones having a different or differently distributed powder flow convergent point in order to select such a convergent point and center of operation for welding using the nozzle **100**. This may also entail a changing of the porous shield cover **210**. However, with the snap ring **214** enabling quick replacement of the porous shielding cover **210** and the outer nozzle **160**, this operation should result in minimal down time for the laser welding device. Additionally, use of the nozzle **100** is not limited to any particular type of laser. The central channel **104** allows the passage of almost any wavelength of light that could be used to energetically excite the welding site.

The present laser nozzle set forth here provides many advantages beyond those laser nozzles previously known. The nozzle **100** eliminates the use of easily-damaged nozzle inserts in order to provide greater up time for welding operations. Additionally, the laser nozzle **100** may be easily dismantled for cleaning purposes and then easily reassembled for quick use for LPF systems. The materials used to create the parts of the nozzle **100** are readily available and machinable in order to obtain a laser nozzle according to the description set forth herein. Consequently, LPF welding operations are made more reliable, predictable, easier, and less subject to interruption by part failure arising in the nozzle.

While the present invention has been described with reference to a preferred embodiment or to particular embodiments, it will be understood that various changes and additional variations may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention or the inventive concept thereof. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to particular embodiments disclosed herein for carrying it out, but that the invention includes all embodiments falling within the scope of the appended claims.